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LEPTOPRODUCTION AT AN SSC FIXED TARGET FACILITY*

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At a recent three day workshop, various aspects of a possible Fixed Target Facility (FTF) at the SSC were examined. This report summarizes the results of a subgroup formed to examine lepton physics within the kinematic bounds allowed with 20 TeV protons on a production target. The group consisted of:

G.	Harigel	CERN
S.	Loken	LBL
J.	Morfin	Fermilab
L.	Stutte	Fermilab
M.	Tannenbaum	BNL

with some theoretical guidance from G. Kane (Michigan).

Our goal at this initial meeting was to organize the group so that we could eventually answer the following questions: what would an FTF do particularly well; what would the increase in energy over the Tevatron bring us; how would the FTF results compare with HERA expectations; and finally what kind of beam intensity and spill structure would be required.

In general, there seems to be no doubt of the contribution which could be made with ultra high energy lepton beams. Leptoproduction has been instrumental in understanding basic nucleon structure. We probably would not understand the quark parton model and QCD as well as we do today without the input of leptoproduction experiments. It may very well be that future lepton beams will be the tool needed to explore possible quark substructure just as contemporary lepton beams have yielded so much information about nucleon structure. An FTF at a 20 TeV accelerator would not only have a high luminosity charged lepton (μ^+,μ^-) facility but also high intensity ν_μ, ν_e and ν_τ beams with which interactions with a particular quark flavor could be emphasized. Following is a brief review of several potential FTF physics topics which could be studied with these beams. It is not meant to be exhaustive, but to stimulate thought for further consideration at Snowmass this summer.

I. Structure Functions

Of the various aspects of leptoproduction which will be discussed in this report, that which seems to best demonstrate the basic need and possible superiority (compared to HERA) of a leptonic FTF is the study of nucleon structure functions. Neutrinos, electrons, and muons have provided the means for a careful study of the nucleon structure function. F_2 has been measured by all three of the above mentioned leptons, and xF_3 by neutrinos, up to a $Q^2 \sim 200\ \mathrm{GeV}^2$. Scaling (approximate) and, with increased Q^2 range, scale breaking were first demonstrated using these lepton beams. It was the Q^2 evolution of the structure functions that provided the first clear test of QCD. What an FTF would add to this study is not just the effective peak Q^2 of ~ 13000 GeV^2 with reasonable statistics, but also the very large range of x_{Bj} and Q^2 available to experimenters.

Within the currently explored Q^2 bounds, the experimental and theoretical uncertainty with respect to higher twist ($1/Q^n$) contributions and other nuclear effects has limited the effective Q^2 range to ~ (25-200) GeV^2. Note that this Q^2 range represents only a factor of 1.6 in ln Q^2 which is the pertinent Q^2 dependence of QCD. By extending Q^2 to 15000 GeV^2 we will not only double the range of $\ln Q^2$ but also permit a measurement of these non-perturbative effects. This could be done by measuring the $\ln Q^2$ dependence accurately in a high Q^2 range (i.e. $Q^2 > 50$ GeV^2) and then extrapolating back to lower Q^2 and measuring the deviation from the expected $\ln Q^2$ values. Figure 1 shows the expected Q^2 evolution (Duke and Owens parameterization) of xF_3 at x=0.55 with and without a twist-4 contribution consistent with our present crude measurements.

This brings us to the first significant advantage of the FTF over HERA. With e^+ and e^- - proton interactions, there are six charged current (CC) structure functions involved and it will be extremely difficult to extract them individually. They clearly cannot be extracted as easily as via the sum and difference of ν and ν-isoscalar target cross sections or muon-isoscalar target scattering. Furthermore in the neutral current (NC) case the Q^2 dependence of the ($\sin^2\Theta_W$ dependent) couplings and the structure functions are intermixed. At HERA, a final model independent solution will only be provided when deuterons are accelerated. This will obviously be a later generation HERA experiment and have a much more limited effective Q^2 range as well as lower luminosity. A further implication of this is the possibility of measuring the Q^2 and A dependence of the "EMC effect" at an FTF which is clearly impossible at HERA.

Another important structure function measurement is the ratio of $xF_1(x,Q^2)$ and $F_2(x,Q^2)$. This ratio determines the absorption of longitudually and transversely polarized Bosons. At best, this is an extremely difficult measurement to perform. From contemporary fixed target lepton beams there are some low energy fixed x results from SLAC, several large error measurements from earlier ν experiments and a very recent attempt by the CHARM collaboration to measure the x dependence of

$$R(x,Q^2) = \frac{F_2(x,Q^2)}{2xF_1(x,Q^2)} - 1.0$$

For fixed target experiments R is obtained by holding x and Q^2 fixed and measuring the cross section at different y by varying the beam energy. This is not the case at HERA since the xF_3 terms do not disappear in the cross section ratios. At HERA one has to measure both $\sigma(e^+)$ and $\sigma(e^-)$ with fixed x and Q^2 at two different values of s. The value of R is then obtained by taking the ratio of the sums. Note that a 5% relative normalization error in the luminosities at the two values of s results in $(\Delta R/R) = 0.1$.

Up to this point we have only compared the basic operating principles of an ep collider and a fixed target facility without discussing detectors and experimental resolution. For comparison of experiment related matters, the report of E. Longo (Univ. di. Roma) presented at the International Workshop on Experimentation at HERA, Amsterdam, June 1983 has been used. Various detectors are specified through their resolution in energy and angle without explicating how these resolutions can be obtained. The so called "ideal" or "perfect" detector is shown in Figure 2. Other detectors with relative degradation in energy and/or angular resolution are also presented. The effect that these resolutions have on the measurement of a structure function of fixed Q^2 is shown in Figure 3. With respect to full QCD fits, the following table summarizes the error in Λ, resulting only from detector resolutions, when a value of 200 MeV is used as input (e = electron, j = jet)

	Detector	$\Lambda_{\text{non-singlet}}$	Λ_{singlet}
NC			
	perfect	200±27 MeV	200±190
	$\sigma(E_e)/E = .1/\ E$ $\sigma(\Theta_e) = 10$mr	200±43	200±210
CC			
	perfect	200±154	200±800
	$\sigma(E_j)/E = .5/\ E$ $\sigma(\Theta_j) = 10$mr	200±180	--

In addition there will be systematic uncertainties which have been quanitized as follows: any of the following errors will change the input value by 50% (200 MeV to 100 or 300 MeV)

a) propagator M_z or M_W wrong by 5 GeV
b) $\sin^2\theta_W$ wrong by .005
c) Relative normalization between E_p=200 & E_p=820 GeV wrong by 5%

This is without other possible sourcces of error such as errors in absolute energy calibration and radiative corrections.

The attainable resolution of possible detectors at the FTF has not been studied to the extent that the projected resolution of HERA detectors has been. This will certainly be a topic to address at Snowmass this year. G. Harigel has described one hybrid detector in detail in a separate report of this workshop. In general the kinematics of leptoproduction at the FTF will be a multi-TeV lepton incoming and scattering off a nucleon constituent resulting in a multi-TeV lepton and/or a multi-TeV hadron shower leaving the interaction vertex. The whole question of resolution with respect to structure functions reduces to how accurately one can measure two of the three four-vectors (ℓ_{in}, ℓ_{out} or h_{out}). In the case of muoproduction the incoming muon can be accurately tagged $\Delta P_\mu/P_\mu \leq 1\%$ and fine grained calorimetry could measure $\Delta E_H/E_H \approx 1\%$ as well as $\Delta\Theta_H/\Theta_H \approx 10\%$, with these figures coming from H. Anderson's ICFA report. Neutrino scattering will be more difficult since knowledge of the incoming neutrino energy will be somewhat limited. As will be explained shortly, narrowband or dichromatic ν beams will be difficult to produce. Thus even though the outgoing hadron shower angle and energy can be accurately measured, a way must be found to measure the outgoing lepton energy and neutrino flux to study structure functions with neutrinos at the FTF.

One further aspect of this topic is the moments of these structure functions

$$M_N(Q^2) = \int x^{n-2} F(x,Q^2)dx$$

It is these moments that are directly predicted by QCD. There have been several experimental difficulties in measuring these moments the most important being; the large smearing corrections and low statistics at high x which are particularly devastating for high N, the extrapolation of the integral from x=0 to $x=x_{min}$ where

$$x_{min} = \frac{Q^2}{2M\nu_{max}}$$

which dominates the low N moment determination. Obviously, the Q^2 range over which these moments can be measured without being adversely affected by x_{min} will be greatly expanded at the FTF.

The question of expected statistics both at HERA and at the FTF is not easy to address. It depends both on the hoped for luminosity and "realistic" duty cycle chosen. Event rates as a function of beam type, spill structure and target at the FTF will be summarized shortly. It has been difficult to find similar event rates for HERA, which have been corrected for loss via the beam pipe, e/π ambiguities, accelerator efficiency etc. However it seems that in general the event rates at HERA and at the FTF will be comparable with effective peak $Q^2 \approx 15000$ GeV^2 for both facilities.

II. Hadronic Shower Structure

The principle advantages of the FTF in comparison to HERA in terms of hadronic shower analysis will be the presence of an intrinsic direction -Q- and a minimal loss of secondaries (limited beam pipe if any). This will allow a detailed look at the Breit frame where independent measurements of α_s should be possible. Recall that whether a particle goes forward (current fragment) or backward (target fragment) in the Breit frame depends on the P_T of that particle with respect to Q. If gluon bremstrahlung takes place, the P_T of that particle with respect to Q increases so that some of the particles which should be classified as forward are incorrectly classified as backward. This creates an inbalance of P_T in the forward Breit frame. Both the amount of the imbalance ($\lesssim Q/2$) and the fraction of events with an imbalance are a direct measure of α_s.

The high particle detection efficiency will enable an investigation of particle fragmentation functions over the complete x, z and Q^2 range and in particular, allow a test of x-z factorization at high Q^2 where non perturbative effects should be small.

III. Like sign Dilepton Production
(information gathered by L. Stutte)

The anomalously high production of like sign dimuons has been seen only in neutrino interactions. It is furthermore the only observed reaction in conflict (factor 5) with the Standard Model. We do not know a great deal about this reaction except that its rate relative to $\nu N \rightarrow \mu^- x$ is about 10^{-3}. The upcoming holographic 15' bubble chamber run could accumulate as many as 50 like sign dileptons so there might be a few hundred accumulated by the time an FTF would be functional. If there are still unanswered questions which require higher energy neutrinos, only the FTF would be able to contribute.

IV. Weak-EM Interference

The measurement of γ-Z^0 interference effects will be one of the more accurate ways of checking the validity of the standard model at high Q^2. One measure of the interference is the difference in $\mu+$ and $\mu-$ cross-sections with given polarization λ. This difference over the sum of the cross-sections is of order $10^{-4} Q^2 (GeV^2)$ so that whereas the effect is $\approx$ .03 at Tevatron energies, values of 0.3-0.5 would be attainable at the FTF. It's interesting to note that for $E_\mu \approx 15$ TeV, a reasonable μ energy with 20 TeV protons on target, the electroweak force actually dominates the electromagnetic (single photon exchange) force over a large part of the kinematic range.

V. Beams, Extraction and Event Rates

There could be a full range of lepton beams at an FTF including bare target and dichromatic neutrino beams, high intensity and controlled polarization muon beams, and exotic lepton beams of of ν_t etc. Currently A. Malensek and I are attempting to construct a beam dump based facility that would be able to produce all of the above mentiooned beams, except the dichromatic ν beam, using a single primary proton transport and minimal secondary beam transport. It capitalizes on the extremely high rate of prompt lepton production (via D and F's) expected with 20 TeV protons on target and thus could eliminate the very costly 10-20 Km long decay pipe needed with conventional beam design. Until this work is complete, quoted rates are from the calculations of S. Mori contained in the previously mentioned 20 TeV ICFA workshop.

For a conventionally designed bare target neutrino beam, Mori assumed a 4Km decay path and predicts ≈ 750 events/10^{13}P in a 100 ton detector of radius r=0.5m with $\langle E_\nu \rangle \approx 4.5$ TeV. The average ν energy can be raised significantly by employing a dog-leg arrangements of dipoles with a collimator upstream of the second bend (Figure 4). Obviously the event rate decreases, however the depletion occurs mainly for $E_\nu \leq 3$ TeV. A dichromatic neutrino beam is, in principle, possible by choosing a narrow momentum band of parent π's and K's. However, to preserve the desired dichromatic feature of E_ν vs R_ν at the detector, very small beam divergence must be maintained. The event rate would be on the order of 50 events / 100 ton-10^{13}p. Mori's beam dump calculations predicted an event rate for ν_τ of $1.2 * A^{1/3}$ where A is the atomic number of the dump material. Thus for a copper dump we would expect 10 events while for tungsten dump we would have 16 events per 10^{13}p for a 100 ton detector. The corresponding rates for ν_μ (= $\bar{\nu}_\mu = \nu_e = \bar{\nu}_e$)are 310 events in Cu and 500 events in tungsten. However, much has been learned about D production since Mori's report was written in late 1979. The cross-section seems to be rising with s and the x_F distribution seems to be much flatter than assumed by Mori. These new observations plus the non-negligible absorption of the D's and F's with 20 TeV protons on target will be taken into account in the new calculations currently underway at Fermilab.

With respect to muon beams, there are several alternatives being considered. The most novel beam would use only the direct muon production which accompanies the ν_μ prompt production mentioned above The dump would act as a conventional target to be followed by a doublet or triplet. The beam thus gathered would pass through a bend and a series of magnetic "scrapers" (such as are being installed in the new Teavtron muon beam) to select the desired momentum bite and reduce the halo. This concept has the added feature that the muon beam elements could act as as active shield to lower the muon background in the prompt ν detectors downstream of the dump. The disadvantage of this scheme, assuming that the muon flux proves to be satisfactory, is the inability to control the polarization of the beam. To do that we must use a more conventional beam which gathers the parent π and K particles, makes the desired momenntum selection, and allows a sufficient decay path along a FODO to get reasonable muon flux rates. Whichever way one chooses to make the muon beam, the following table taken directly from H. Andersons ICFA report summarizes the expected event rates for 10^{40} μ^+ x nucleons/cm². This is roughly equivalent to 10^{18} (10^{17}) p on the production target with a 10m(1m) long D_2 (Fe) target. Note that the y ≥ 0.2 cut eliminates a fair fraction of the low Q^2 (≤ 800 GeV^2) events.

y \ x	0 – .2	.2 – .4	.4 – .6	.6 – .8	.8 – 1.0
.2 – .4	384610	53600	5525	505	13
.4 – .6	592570	12060	1140	100	2
.6 – .8	889110	4125	350	30	1
.8 – 1.0	1444500	1575	105	7	--

μ^+ event rates (y > 0.2) for 10^{40} muons x nucleons/cm². Total μ^+ events = 3.39×10^6, correspondng μ^- = 3.53×10^6

The details of the various spill modes considered at the workshop will be related in the report of A. Bodek. Here are summarized the consequences of the different modes. Since the collider will probably dump "old" beam and refill every twelve hours or so, a slow parasitic extraction where 10^{14} p are dumped over ≈ 100 seconds twice per day would have essentially no effect on the collider program. A dedicated slow spill could be as many as 2 spills/hour with 10^{14}p over 100 seconds. A third possibility is a dedicated ping beam which would distribute the proton intensity more evenly in time. One could have ≈ 100 pings/hour of length 3 μsec. The intensity per ping would be dictated by the maximum instantaneous event rate an experiment could handle and the detector target mass. For example, If the data acquisition facility of a ν experiment could handle 5-10 events/ping then with 2×10^{12} p/ping either the detector mass would be limited to ≈ 10 tons with the bare target beam or to ≈ 100 tons with a narrow band beam.

To summarize one would expect the following event rates per "week" where a "week" is an effective 110 hours of combined accelerator and detector running i.e. 2/3 combined efficiency. The entire extracted proton intensity is assumed to be dedicated to the beam in question.

Neutrino Beams (100 ton detector, r=0.5m).

	Beam Type	Extraction	Events
1.	Bare Tgt	slow parasitic	70000
		slow dedicated	1630000
		ping(2×10^{12}p/ping)	110000(10 ton detector)
2.	Dichromatic	~ (5-10)% of the above	
3.	Beam Dump (tungsten)	slow parasitic	ν_τ:1500
			$\overset{(-)}{\nu}_\mu, \overset{(-)}{\nu}_e$:47300 each
		slow dedicated	ν_τ:35250
			$\overset{(-)}{\nu}_\mu, \overset{(-)}{\nu}_e$:1100000 each

Muon Beam (15 TeV, μ^-/proton = 0.5 μ^+/proton)

Target	Extraction	Events ($y > 0.2$)	
Fe-1m	slow parastic	μ^+:	34000
		μ^-:	18000
	slow dedicated	μ^+:	782000
		μ^-:	415000

D_2-10m ≈ 0.1 x above rates.

For a direct comparison between HERA and the FTF muon beam the following table summarizes the event rates for the kinematic region $x > 0.2$ and $y > 0.2$. For HERA $L = 5 \times 10^{31}$ is assumed as well as the 2/3 combined efficiency assumed at the FTF. Muon rates are for the 10m D_2 target so should be multiplied by 10 for 1m Fe target. The five entries in each box correspond to: (events per "week")

HERA (from L. Maiani's Report)
$\mu^- D_2$;slow parasitic
$\mu^- D_2$;slow dedicated
$\mu^+ D_2$;slow parasitic
$\mu^+ D_2$;slow dedicated

y \ x	.2 – .4	.4 – .6	.6 – .8	.8 – 1.0
.2 – .4	32.6	6.1	0.7	--
	30.8	3.5	0.4	--
	710	80.0	7.7	0.2
	53.6	5.6	0.5	--
	1230	127	11.7	0.3
.4 – .6	16.6	2.6	0.2	--
	8.9	1.1	0.1	--
	205	23.8	2.3	0.2
	12.0	1.1	0.1	--
	275	26.2	2.3	--
.6 – .8	9.8	1.4	0.2	--
	4.2	0.5	0.1	--
	95.0	11.5	1.1	0.1
	4.1	0.4	--	--
	94.9	8.1	0.7	--
.8 – 1.0	6.8	0.9	--	--
	2.1	0.3	--	--
	48.1	5.1	0.4	--
	1.6	0.1	--	--
	36.2	2.5	0.2	--

In general, the average Q^2 in a given x-y bin will be higher at HERA than at the FTF.

VI. Conclusion

It is hoped that this brief review of potential physics at SSC fixed target facility will serve as a basis for further discussion at Snowmass this summer. In general, preliminary indications are consistent with an FTF-Detector combination performing at least as well and in many cases decidedly better than currently envisioned HERA facilities. This, however, must be confirmed by less approximate calculations and careful consideration of likely FTF detectors.

References

HERA: All HERA related information in this report came from the Proceedings of the Workshop Experimentation at HERA, Amsterdam, June 9-11. DESY Publication 83/20. In particular the contributions of:

E. Longo, "Currents and Structure Functions", pg.285
L. Maiani, "The Virtues of HERA", pg.3
D.H. Perkins, "Lepton-Nucleon Collisions", pg.39

ICFA: The various International Committee for Future Accelerators (ICFA) reports referred to come from: Proceedings of the Second ICFA Meeting. Les Diablerets, Switerzerland, 1979.

H.L. Anderson, "Muon Spectrometer for E_μ = 15 TeV", pg.299
G. Barbiellini, "Deep Inelastic Experiments" pg.289
S. Mori, "Neutrino Beams in the Energy Range of 20 TeV", pg.333

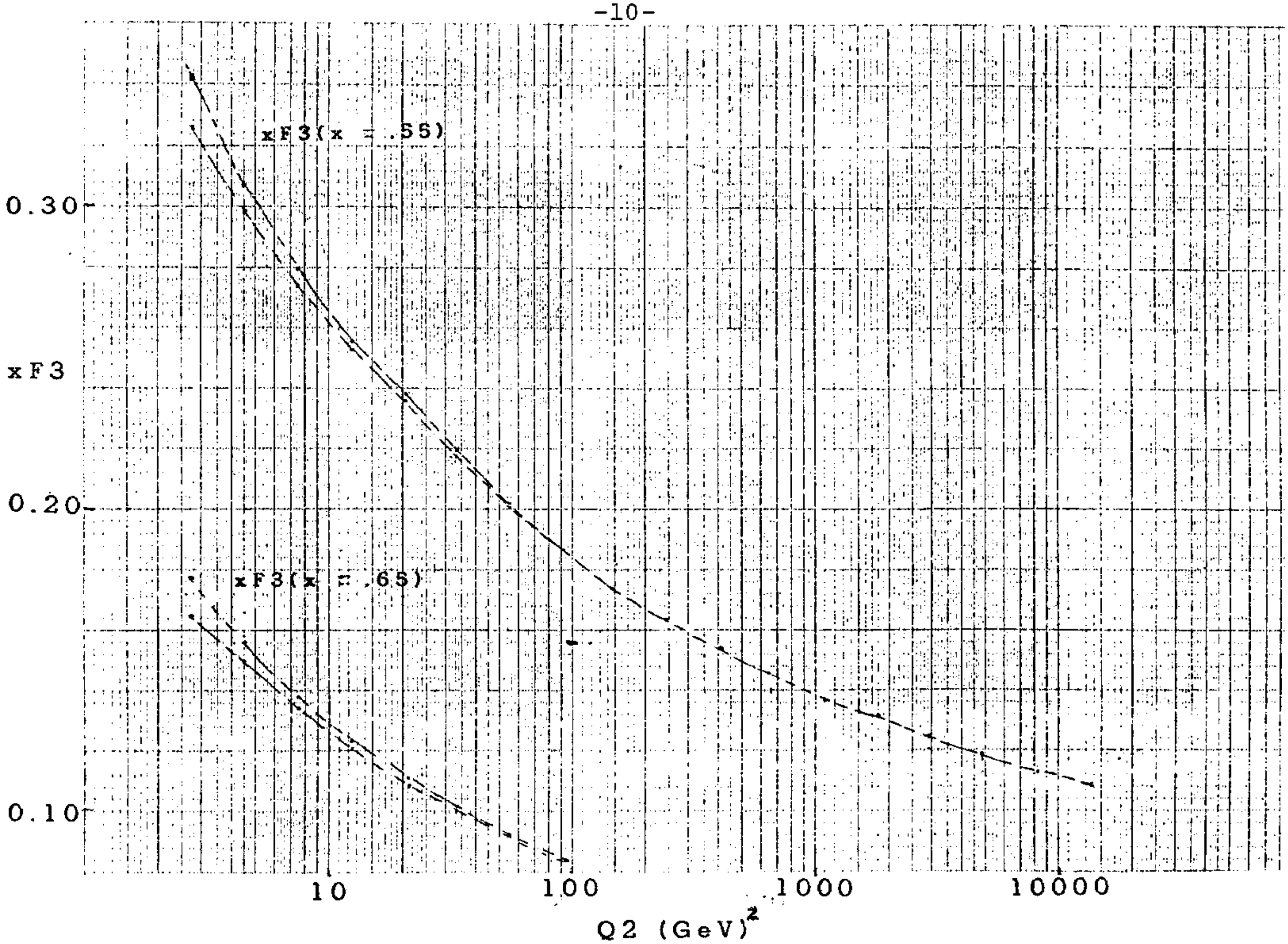

Figure 1 - XF_3 vs Q^2 for x = 0.55. The upper curve is pure QCD while the lower curve includes an estimated twist-4 contribution.

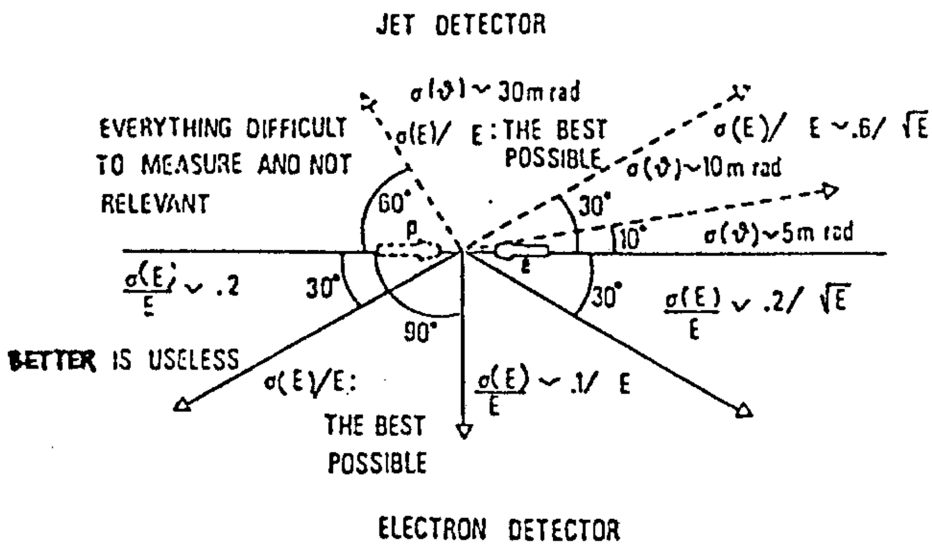

Figure 2 - From E. Longo's report. The "ideal" HERA detector referred to in the text.

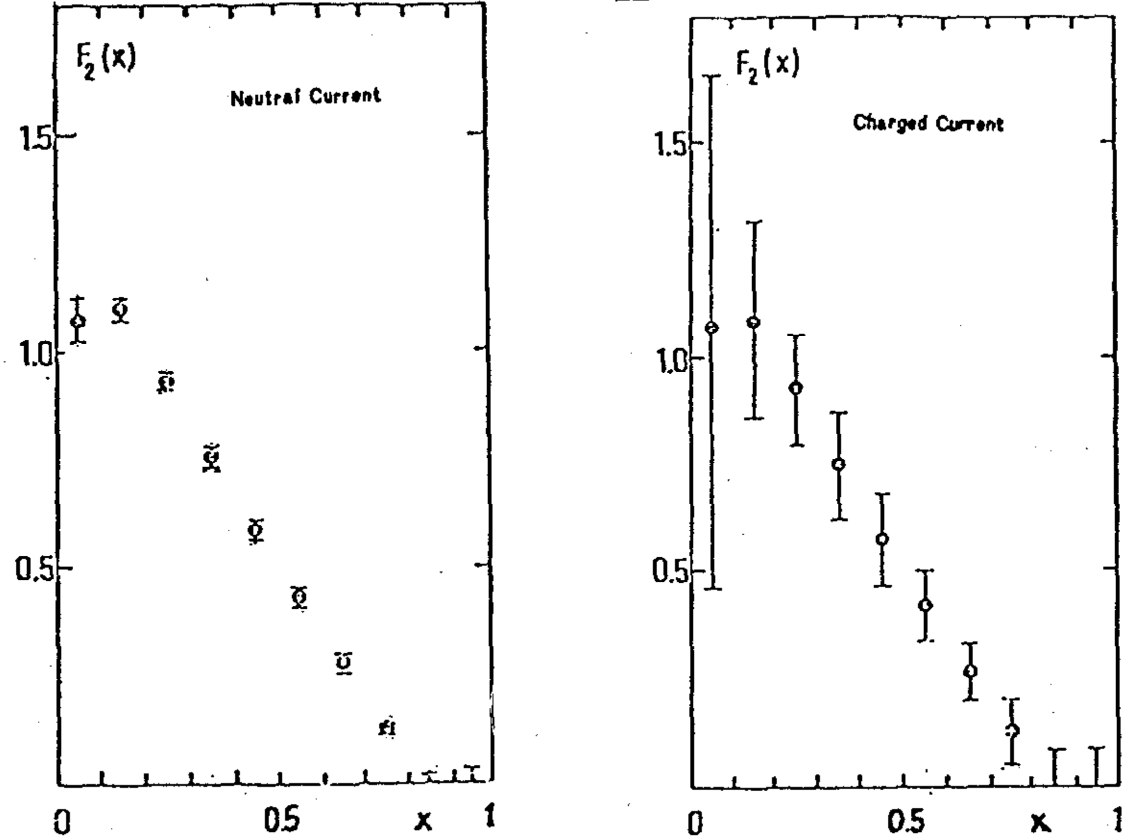

Figure 3 - From E. Longo. Uncertainity in determining $F_2(x)$ at fixed Q^2 coming from the "ideal" detector i.e. no statistical error.

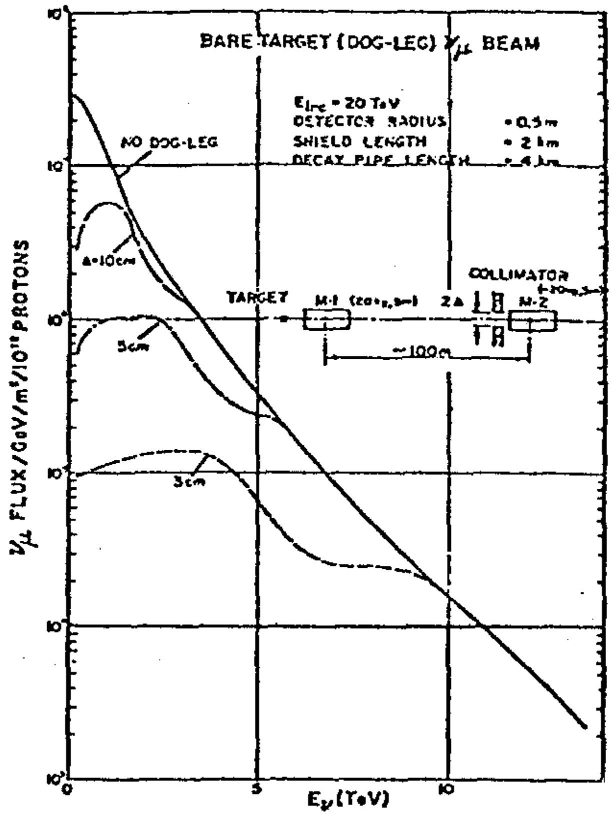

Figure 4. Muon neutrino fluxes as a function of a beam collimator aperture in a dog-leg arrangement. The detector radius was 0.5m and the incident proton energy was 20 TeV. From S. Merl.